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13. ABSTRACT *(Maximum 200 words)*

The main results of six experiments are as follows: (i) pitch-streaming does not appear to affect polyrhythmic performance; (ii) the data show timing dependencies between the hand except when visual information was blocked; (iii) subjects performed well at high speeds keeping to within 10% of the desired speed, but details of performance suffered leading to greater instability in rhythmic performance; (iv) on the few occasions when the 5:3 rhythm became unstable, performances shifted towards a 2:1 polyrhythm.

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FINAL TECHNICAL REPORT

"Training to Study Coordinated Motor Acts "

AFOSR AASERT Grant No. F49620-97-1-0394

October 31, 2000

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2. Objectives (period covered 1 JUN 97 - 31 AUG 00)

This proposal describes a training program that taiught potential life scientists (one Graduate student and several undergraduate students) how to study the way a human being coordinates actions of the head, eyes and hands while manipulating devices that control events. Such coordinated actions are used in modern hi-tech settings, including crew workstations. They are also used to control outputs of more humdrum devices, such as the keyboard of a typewriter or wordprocessor, the body and buttons of a mouse connected to a PC, and the valves, strings and keyboards of musical instruments.

The laboratory, in which the **AASERT** students were trained, houses a unique instrument, the Maryland Revolving Field Monitor (**MRFM**). This instrument measures 3-D angular rotations of the head and eyes, and 3-D translations of the head. The **MRFM**'s spatial and temporal resolution and accuracy is better than any other instrument and, more important, at least a factor of 2 better than the biological systems human beings use to control movements of the head and eyes.

One Graduate Research Assistant (**GRA**) was supported during the period covered by this report. Namely, Sally Bogacz, who Was a Doctoral Candidate in the SensoriNeural and Perceptual Processes Specialty (**SNAPP**) at **UMCP** when she entered this training program. Ms. Bogacz had had considerable prior training to perform highly complex manipulations. Specifically, she received 18 years of violin and 15 years of piano training in London before coming to the USA, where she is now a naturalized citizen. Her training included 4 years at the Royal College of Music and 3 years at the Guildhall School of Music. Ms. Bogacz's motor skills, coupled with her graduate-level training in Psychology that prepared her to study motor control, made her a particularly valuable addition to our research team.

The **AASERT** grant also supported several Undergraduate Research Assistants (**UGRA**s), who worked 10 to 20 hours each week. They were recruited from the population of students enrolled in our undergraduate Honors Programs.

Sally Bogacz defended her doctoral dissertation on July 25, 2000 and turned her completed dissertation into the Graduate School at the University of Maryland on August 31, 2000. Ms. Bogacz will graduate with her PhD in Psychology in December, 2000. Her dissertation research and current activities are described in some detail below.

Four undergraduate Research Assistants, who were supported, in part, by this training grant, graduated during the period it was in force, namely, Brian Donaldson, Sunny Edwards, Andrew Herst and Tova Benederet. Two of the three (Herst and Edwards) are currently enrolled in graduate programs in Psychology. Both graduated with Honors in Psychology, Benederet will enter Medical School in September 2001, and Donaldson is currently studying computer programming as a special student. They all graduated with distinction, specifically, Herst received his BS in Psychology *Magna cum laude* and was on the Deans List between 1995-98; Benederet graduated *cum laude* with Honors in Psychology and shared the Mark Harper Award for the most outstanding graduating major.

3. Status of the Final Effort: (June 1 1999- August 31, 2000)

During the summer (June 1-August 31, 1999), Ms. Bogacz refined the experimental design for her dissertation and ran two experiments on expert subjects. These expert subjects were professional pianists recruited from the Music School at the University of Maryland. The first experiment was a replication of Bregman & Campbell (1971) to determine if the subjects were susceptible to the "pitch-streaming" effect. Pitch streaming occurs whenever two successive pitches are not heard successively, but rather "split" into two different streams. This happens when pitch-intervals are large and the pitches are presented at fast speeds. This experiment showed that pitch-streaming did occur under the predicted conditions and that this effect interfered with the subjects ability to make judgments about the ordering of tones.

The second experiment was designed to test whether pitch-streaming had an effect on polyrhythmic performance. In this experiment, subjects played polyrhythms on a piano keyboard, with one hand playing a "3" at the same time as the other plays a "2" (3:2 polyrhythm) and with one hand playing a "5" at the same time as the other plays a "3" (5:3 polyrhythm). The subjects were instructed to play these polyrhythms at several different speeds ranging from a speed that seemed moderately slow (3 notes/s) to one that seemed extremely fast (16 notes/s). Pitch-intervals were varied to see if pitch-streaming had an effect on performance. We found that it did not. In addition, performance was remarkably good at high speeds on both global speed measures (which measured a subject's ability to keep to the desired tempo) as well as overall measures of rhythmic performance. Surprisingly, subjects appeared to have more problems on both these measures at slower speeds.

Throughout the Fall, Ms. Bogacz ran Experiments 1 and 2 on non-expert subjects and designed and ran a new experiment on both experts and non-experts. The non-experts were Psychology Graduate students who had received piano lessons as children, but had not played piano for many years. We decided not to recruit novices on the grounds that the task was too difficult, and the data might be unreadable. The data gathered from non-experts on Experiments 1 and 2 were indistinguishable from the data gathered from experts. Non-experts were just as susceptible to the pitch-streaming effect in the perceptual setting of Experiment 1, but it had no effect on the polyrhythmic performance measured in Experiment 2. As with experts, non-experts performed remarkably well at high speeds and appeared to have more difficulty at slow speeds.

Experiment 3 was designed to examine this phenomenon more closely by studying performance on the 5:3 polyrhythm (because it was more difficult than the 3:2) at speeds ranging from 1 note/s (which seems extremely slow) to 12 notes/s. (Prior performances at 12 notes/s were indistinguishable from those at 16 notes/s). The results were similar to those of Experiment 2: Both experts and non-experts performed remarkably well at high speeds and had more difficulty at slow speeds. For example, standard deviations for overall speed accuracy showed more variability at slow speeds than at high speeds. In addition, correlational analysis derived from the models of Jagacinski *et al.* (1988) showed that there was a timing dependency between the hands, suggesting that subjects were using an "integrated strategy" in which they treated the polyrhythm as one thing rather than a "parallel strategy" in which they treated the polyrhythm as two.

During the Spring, Ms. Bogacz ran three more experiments on both experts and non-experts

to: (i) check for the robustness of the phenomenon and (ii) try to explain it. In addition, she began to do the writing necessary to complete her dissertation. Experiment 4 was designed to control for practice effects. In both Experiments 2 and 3, subjects had played polyrhythms by going from slow to fast. Experiment 4 changed the order of polyrhythm presentation to check that superior performance at high speeds was not due to practice. The results were more or less identical to Experiment 3: Subjects continued to perform well at high speeds and had more trouble at slow speeds, and correlational data showed timing dependencies between the hands.

Experiment 5 was designed to see whether superior performance at high speeds was due to *lack* of interference from the perceptual systems. In this experiment, two subjects performed the 5:3 polyrhythm as a duet, both sitting in front of the piano keyboard with one person's hand taking one line (*e.g.* the "3" of the 5:3) and the other person playing the other line (*e.g.* the "5" of the 5:3). The results were more or less identical to those for Experiment 3: Subjects gave remarkably good performances at high speeds and had more problems at low speeds, with timing dependencies between the hands.

Experiment 6 investigated how performance deteriorated when visual information was blocked. The task for Experiment 6 was exactly the same as that for Experiment 5, except that both subjects performed with blindfolds. The results show that rhythmic performance suffered at high speeds, and that the timing dependency between the hands was lost.

The main results of these 6 experiments are as follows: (i) pitch-streaming does not appear to affect polyrhythmic performance; (ii) the data show timing dependencies between the hands, except when visual information was blocked in Experiment 6; (iii) subjects performed well at high speeds keeping to within 10% of the desired speed, but the details of performance suffered leading to greater instability in rhythmic performance; (iv) on the few occasions when the 5:3 rhythm became unstable, performances shifted towards a 2:1 polyrhythm.

In May, Ms. Bogacz turned in a preliminary version of her dissertation and then began to do more extensive analyses of the data. In June and July, Ms. Bogacz made revisions to the preliminary version of the dissertation, and then prepared for her dissertation defense. The dissertation defense was held on July 25th at the University of Maryland. Committee members included Dr. Willard Larkin (chair) and Professors Robert Steinman, Steven Brauth and William Hall from the Psychology department, and Professor Avis Cohen from the Biology department. The committee voted to pass Ms. Bogacz, subject to some minor revisions. During the last days of July, Ms. Bogacz met with each committee member separately to discuss the proposed revisions, and then made those revisions.

In August, Ms. Bogacz attended the 6th International Conference on Music Perception and Cognition, held at Keele University, England from August 5-10. This conference brought together experts from Psychology and Music to discuss various aspects of music listening and performance. Ms. Bogacz had an opportunity to hear Caroline Palmer discuss how meter influences memory and planning processes in performance, Carol Krumhansl describe how listeners are able to follow modulations in music, Dirk-Jan Povel discussing a computational model that describes on-line processing of music, Aaron Williamon describe how non-verbal communication is developed when two pianists are practicing together as a duo and Peter Keller describe how musicians allocate

attentional resources when playing together in an ensemble.

In addition, Ms. Bogacz gave a talk at the conference titled "Cognitive and motor coordination of polyrhythms in piano performance" in which she described the main results of her dissertation. This gave Ms. Bogacz a valuable opportunity to present her work in a professional setting as well as to obtain useful feedback from experts in the field, such as Caroline Palmer, who attended her talk.

In late August, Ms. Bogacz completed the necessary revisions to her dissertation and turned the completed manuscript into the Graduate School at the University of Maryland on August 31, 2000. Ms. Bogacz will graduate with her PhD in Psychology in December, 2000.

Summary of Participation at conferences.

Talk given at 6th International Conference on Music Perception and Cognition, Keele, UK, August 5-10, 2000: *Cognitive and motor coordination of polyrhythms in piano performance.*

Personnel.

Sally Bogacz was the only graduate stdent supported by the AASERT Grant during the period the AASERT Grant was in force. Support included her stipend and expenses associated with her participation at one conference, at Keele, UK. Four undergraduate Research Assistants, who were members of the Psychology Honors Program, received their BS degrees in Psychology after having had partial support on this training grant, namely, Brian Donaldson, Sunny Edwards, Andrew Herst and Tova Benederet. Two of the three (Herst and Edwards) are currently enrolled in graduate programs in Psychology, Benederet will enter Medical School in September 2001, and Donald son is currently studying computer programming as a special student. All graduated with distinction (see Section 2 above).

References.

Jagacinski, R. J., Marshburn, E., Klapp, Stuart T. & Jones, Mari R. (1988). Tests of Parallel versus Integrated Structure in Polyrhythmic Tapping. *Journal of Motor Behavior, 20(4)*, 416-442.